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FACULTY WORKING
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On the Optimum Number and Location of Controls in Accounting Information Systems

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University of Illinois, Urbana-Champaign

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On the Optimum Number and Location of Controls
in Accounting Information Systems

ABSTRACT

Management's responsibility for designing adequate and effective controls in the accounting information systems (AIS) has recently increased due to the Foreign Corrupt Practices Act (]977). The choice of an appropriate design (number and location) of controls for the AIS involves a tradeoff between cost and reliability of the system. Using the systems concept, this study presents a dynamic programming model to help management resolve this tradeoff by identifying a easible set of decisions (designs) of control for the AIS with serial and nonserial configurations. A coputer program has been developed for the application of the model to a hypothetical payroll system. The preliminary results suggest that the location rather than the number of controls has a significant effect on the reliability and cost of the system. Sensitivity analysis showed that reasonable changes in the accounting environment would not significantly affect the results of the model.

ON THE OPTIMUM NUMBER AND LOCATION OF CONTROLS IN ACCOUNTING INFORMATION SYSTEMS

In the business environment, several parties are concerned with one or more aspects of performance of the accounting information system (AIS). Management and internal auditors, for example, are concerned with the cost of the AIS, and the accuracy, timeliness and perhaps the quantity of the accounting information it produces. On the other hand, external auditors are usually concerned with the reliability (or error rate) in the accounting information produced and how control functions are performed in the system. These aspects of performance are greatly affected by the number and location of the accounting controls that are built into the AIS to reduce the error rate in the accounting information processing and consequently reduce the loss from reprocessing, correcting and/or using the materially incorrect information. Therefore, the analysis of the performance of the AIS would necessarily require an analysis of the accounting controls that are placed into the system. An ex post analysis may help the analyst assess the effect of such controls on the overall cost and error rate in the accounting information produced by the system. However, a tool (i.e., model) to be used in an ex-ante analysis is needed to help the analyst (manager or auditor) determine an appropriate number and location of controls to be placed in the system such that its performance parameters (i.e., cost and error rate in the accounting information) are within acceptable limits.

Management's concern about the design of controls in the AIS is based on two premises: its responsibility for establishing and maintaining effective accounting controls to comply with the Foreign Corrupt Practices Act [1977], and its assumed objectives of obtaining reliable accounting information for a minimum cost. Internal and external auditors will need such tools when, as a special engagement, they are asked by managment to provide suggestions about how to increase the effectiveness of accounting controls or how to improve the overall performance of the AIS.

This study applies the systems concept to the problem of designing controls in th AIS. A dynamic programming model has been developed to help managers and internal and external auditors identify a feasible set of control decisions (i.e., designs of number and location of controls) in the AIS. A hypothetical payroll system was used to illustrate the application of the model. The preliminary results suggest that the location rather than the number of controls has significant effects on the cost and error rate in the AIS. Another observation is that the end of a process (phase or stage) in the AIS seems to be a good location for control. Sensitivity analysis showed that reasonable changes in the accounting environment (i.e., growth or cost increase) would not affect significantly the results of the model.

PREVIOUS RESEARCH

Traditional techniques of analyzing the performance of the accounting information systems such as questionnaires, flowcharts, and tests of transactions have been criticized for their nonuniformity, cost and time required for their application, and their subjectivity [Loebbecke and Zuber, 1980]. In using those techniques, the analyst or manager cannot systematically assess the effect of the weakness of a control in the system on the system's overall performance. Yu [1972] summarized some of these instances:

> 1) If the analyst finds a weak control area from the questionnaires and flowcharts, he can rarely point out precisely the impact of such weak control on the reliability of the system as a whole, 2) errors discovered by the analyst during the tests of transactions are not used in any systematic way in assessing what has been initially revealed by the questionnaires and flowcharts, and 3) the analyst (e.g., the auditor) may frequently have difficulty in defining errors when applying statistical sampling methods. He also has no means to relate various test results to each other.

A number of quantitative models were recently presented into the accounting literature for the analysis of accounting controls. With the growing interest in the systems concept and its applications in accounting, Stallman [1972] developed a quantitative model to measure the total cost of errors in an existing accounting control system. Yu and Neter [1973] introduced a Markovian model to help assess the reliability of accounting controls. Applying the engineering concept of reliability, Cushing [1974] presented another model for reliability assessment of accounting controls. Bodnar [1975] extended Cushing's model to evaluate the effect of parallel channels vs. parallel controls (or redundancy of controls) on the overall reliability of the system. His analysis provided new insights for the design of accounting controls. He also discussed the special problems inherited in the application of reliability engineering models to the human elements in the accounting systems. Hamlen [1980] presented a chance-constrained mixed integer-programming model for internal control design. The model is designed to minimize the cost of the system subject to the quality desired in the accounting information (i.e., minimum goals for error reduction). Hamlen's model, however, does not provide an overall rate of performance in the system. In addition, the model can handle only a limited number of processes in order to limit the number of constraints that must be added when the number of variables increases. These models have contributed significantly in the understanding of the issues involved in the analysis of accounting controls. They also helped in uncovering some of the problems in measuring quantitatively the performance attributes of accounting controls. None of these studies, however, was concerned with the design (number and location) of controls in an AIS with non-serial configurations such as converging or diverging branches (channels) or feed forward loops which are common in the real AIS. Furthermore, they do not provide alternatives (a set of designs or range of choices) for the system designer (management) to choose the design (number and location of controls) which is most appropriate for the management's acceptable limits of cost and error rate in the AIS.

In his description of the characteristics of controls, Neumann [1981] provided general guidelines for locating the controls. He suggested the following locations for controls: "1) prior to a particularly expensive portion of a project; 2) preceding points of no (or difficult) return; 3) at the point at which one phase terminates and another begins; 4) points where measurement is more convenient; 5) points at which it may be easier to take corrective action; 6) points that still provide ample time for corrective action; and 7) following a complex task or completion of an error-prone activity." In the absence of a model that would quantify the effect of each of these suggested locations on the overall performance of the system, the choice of location of controls is a highly subjective decision and may lead to nonoptimal solution with unacceptable performance of the system (i.e., unacceptable error rate or cost in the accounting information). The need for a new model has been acknowledged [Peat, Marwick, Mitchell and Co., 1976] and as indicated by Felix [1981], little progress has been made in this regard.

The objective of this paper is to apply the systems concept to the analysis of the number and location of controls in the AIS. Specifically the paper develops a dynamic programming model to be used as a decision support system to help identify a possible set of dominating designs of controls and to measure the effect of each design on the performance of the AIS. A side objective is to develop a computer program for the application of the model to a general class of systems with serial (a series of components) and nonserial (branches or loops) configurations. To illustrate the applicability of the model and the program, a hypothetical AIS will be analyzed.

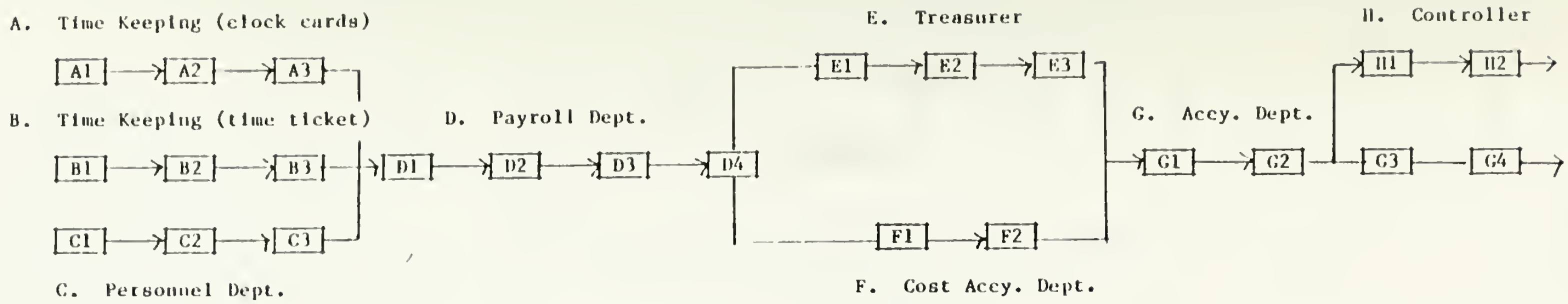
RELEVANCE OF THE SYSTEMS CONCEPT FOR THE ANALYSIS OF AIS

The systems concept views any system as a group of elements each of which performs some function(s) which are designed in a specific order to meet end results. The concept emphasizes the importance of the element's performance for the overall performance of the system. It concentrates on the definition of functions and the flow of the process and not primarily the final output.

In this concept more consideration is given to what happens in between the input and the output points. Applying this concept to the AIS requires a description of the elements, functions, and processes involved.

An accounting information system (AIS) consists of operating components and control components. Operating components perform accounting functions such as computing and writing payroll checks, recording a purchase, or preparing financial statements. Control components, on the other hand, check on the correctness of the accounting process. In performing their functions, operating components can introduce errors into the accounting information process while control components are designed to reduce these errors.

To understand the relevance and application of the systems concept to the design of accounting controls, consider the hypothetical payroll system shown in Figure 1. This system includes operating components designed in four types of configuration: converging branches, a series of component, feedforward loops, and diverging branches. Each configuration can be viewed as a stage in the system. Accounting information processing is performed in five consecutive parts (stages) in this system. The output information from each stage is the input information to the next stage in the system. Therefore, our AIS can be viewed as a five-stage process in which stage 1 is a number of converging branches, stage 2 is a series of components, stage 3 is a number of feedforward loops, stage 4 is another series of components and stage 5 is a number of diverging branches. The sequence of the stages in our system example is shown in Figure 2.



A,B
Time Keeping Dept.

A1: Record beginning time
A2: Record ending time
A3: Compute the time worked after the allowed breaks

B1: Record names workers on a given job
B2: Enter amount of time spent by each worker
B3: Prepare a time ticket for each job

C
Personnel Dept.

C1: Prepare name cards for people on the job
C2: Prepare the "per hour" (regular and overtime)
C3: Prepare the deductions for each employee

D
Payroll Dept.

D1: Prepare payroll register (names, rates, hours)
D2: Compute payroll
D3: Assign costs to time tickets
D4: Write payroll checks

E
Treasurer

E1: Enter the number of pay checks onto the payroll register
E2: Sign the paychecks
E3: Distribute paychecks

F
Cost Accg. Dept.

F1: Compute job and/or process cost
F2: Update inventory records

G
Accg. Dept.

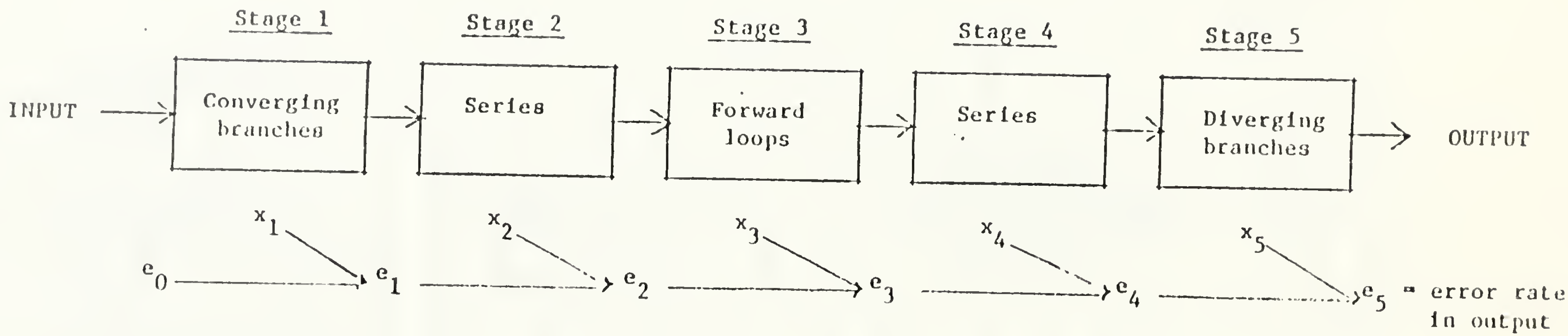
G1: Record payroll expense for the period
G2: Prepare payroll report
G3: Make adjusting entries for reconciliation statement
G4: Update cumulative records of payroll

H
Controller

H1: Prepare reconciliation with payroll bank statement
H2: Analyze payroll reports

Figure 1

A Hypothetical Payroll System



e_k = error rate in the output from stage k

x_k = decision (number and location of controls) in stage k

Figure 2

Stages of the Payroll System Example

This problem of designing the appropriate controls into this multistage accounting process (system) fits the nature of dynamic programming which is an optimization procedure that is particularly applicable to problems requiring a sequence of interrelated decisions. Each decision transforms the current situation into a new one. A sequence of decisions, which in turn yields a sequence of situations, is sought in order to optimize (minimize or maximize) some measure of value. The relevance of dynamic programming to the accounting control design problem is, therefore, based on several analogies: 1) the sequential nature of accounting information processing, 2) the need for making sequential decisions regarding accounting controls, 3) the cumulative effects of such control decisions on the errors and cost of the accounting information, and 4) the need for a quantitative tool for the minimization of the total cost of the system given the available sets of controls (decisions) to maintain the acceptable limits of the error rate in the information.

Error Analysis

Possible errors in accounting systems may be classified into two types: errors which reduce the accuracy/reliability of financial reporting, and errors which reduce the efficiency/effectiveness of the organization management. Examples of the first type include errors in the amount computed or recorded as payroll expense for the period, or in recording the correct amount in an incorrect account. On the other hand, errors in signatures, names, social security number and other non-monetary data on payroll checks are examples of the second type of errors which reduce the confidence in the organization policies and systems. However, for the analysis of the required controls definitions of specific possible errors are needed. The task of defining these possible types of errors is that of the system designer (i.e., management). The analysis of the required controls will be performed basically with respect to each error. This would help the system designer to apply the concept of materiality to each error separately.

The Optimization Process

The cost to be minimized in this study is the total cost of errors in the system. The total cost of errors include the following costs:

a) Costs of processing/correcting erroneous information

b) Cost of detecting errors (i.e., cost of installing and operating control elements to detect the existing errors)

c) Cost of misinformation (loss from using incorrect information)

The first two costs are operating costs which are reasonably easy to define since their data is usually recorded for financial reporting purposes. But the third cost may not be as readily determinable.

The cost of misinformation is a function of the decision model that uses this information. Decision models and utility functions to be considered in decision making may differ according to the decision maker. However, this function may generally include variables such as the type of error under analysis, the error rate in the information, and the stage of the system where the error exists (i.e., how far in the system the error went undetected). Therefore, the monetary loss of misinformation is mostly based on these variables.

By adding controls to the system the error rate or the probability of information failure is expected to decrease. As a result, the operating cost of errors (i.e., the cost of processing incorrect or unacceptable information) and the cost of misinformation, will both increase because they are functions of the error rate in the information. On the other hand, the total cost of the system will increase by the cost of installing and operating these additional controls. The total cost effect of adding controls into the system is the total cost of errors, and is illustrated in Figure 3.

Although the cost of the AIS is an important consideration to management, its primary interest is the reliability/accuracy of the accounting information produced by the system. Hence, management's decision concerning the design of controls involves a tradeoff between the cost and the error rate in the information produced. To help management make the choice, the model provides a set of feasible designs of controls to help management resolve this tradeoff such that the resulting error rate and cost of the accounting information are acceptable. This set of designs can be described as the dominating control decisions in the optimization process, and is shown in Figure 4.

In this figure, the set A includes the feasible decisions (designs) of control. All the possible designs to the left of point S will provide higher error rates for higher cost. Therefore, the dominating decisions of controls are included to the right of point S. How far can the set A extend to the right of point S depends on the maximum total cost that management is willing to accept.

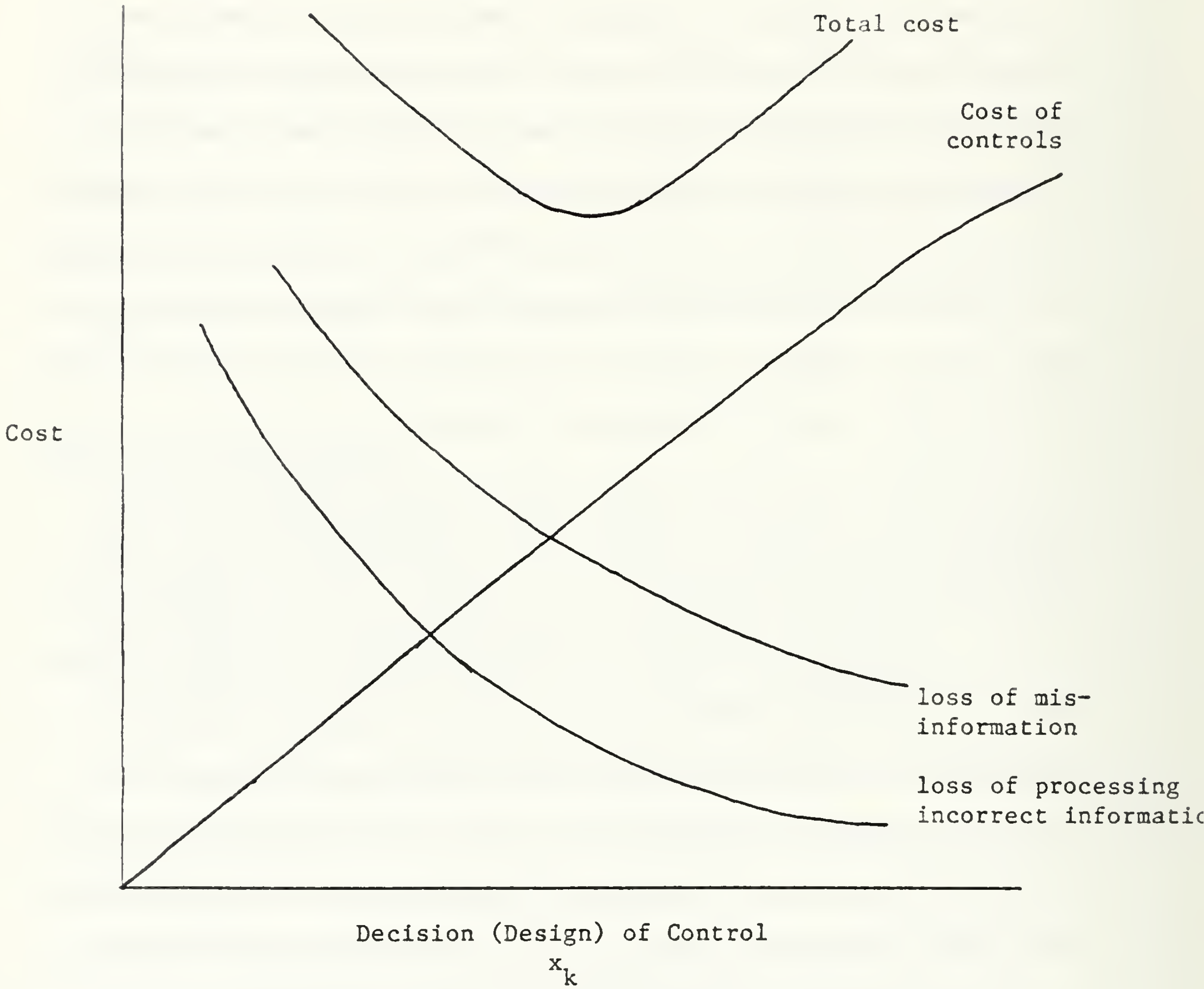


Figure 3

Total cost of errors: Optimization Target

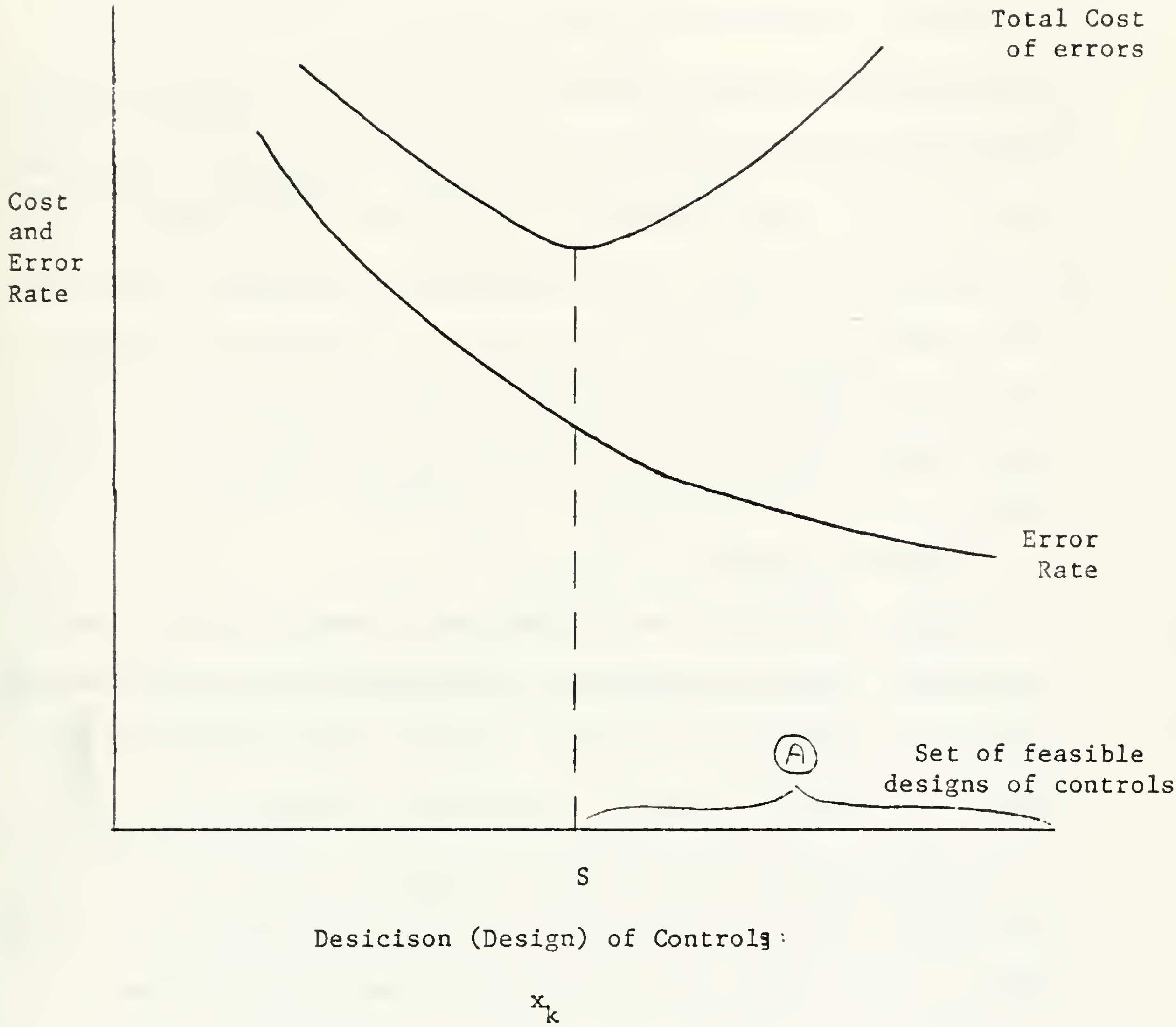


Figure 4

The Feasible Set of Control Designs

MODEL DESCRIPTION

The dynamic programming representation of any optimization problem requires the definition of seven constructs: the stages of the system (process), the states (conditions) in which the system might be found, the decision set (choices) that can be made in each stage, the state transformation function, the constraints on optimization, the stage return function, and the recursive equation(s). For the accounting information system, these constructs can be defined as follows:

1) The stage of the AIS:

As shown in Figure 2, our system example consists of five configurations. Each configuration is defined such that it includes one phase of the accounting information process. This configuration (phase) is defined as a stage in the system. Define k; k=1, 2, ..., k as the index for the five stages of the system. The accounting information that is the output from stage 1 is the information that is the input to stage 2 and so on. Each stage of the system includes B_k branches; $b_k = 1, 2, ..., B_k$, where b_k is branch b in stage k.

2) The states of the AIS:

The states of the AIS can be defined in terms of the error rate in the accounting information being processed. Let e_{tk} be the rate of type error t in the accounting information processing at the end of stage k. That is e_{t0} is the state of the system (i.e., the rate of error t) at the beginning of stage 1 and e_{t1} is the rate of error t at the end of stage 1. Similarly the state of the system concerning error t at the end of stages 2, 3, 4, 5 are denoted e_{t2}, e_{t3}, e_{t4}, and e_{t5} in our example, where the state of the system e_{t5} describes the rate of error t in the final information output. The state of the system at the end of stage k (e_{tk}) is a function of the combined error rate from the different branches in the stage (e_{tb_k}). That is

$$e_{tk} = f(e_{tb_k}),\ b = 1, 2, \ldots, B_k \tag{1}$$

On the other hand, the error rate at the end of branch b_k is a function of the combined error rates from the different components in this branch. In other words $e_{b_k} = f(e_{tib_k})$; $i = 1, 2, \ldots, m_{b_k}$ where m_{b_k} is the number of operating components on branch b_k. Since the analysis of the system will be performed for each of the predefined errors, we now drop the subscript t considering that all terms are stated for this given error.

3) The decision set:

The control decision at hand is to optimally choose and place a number of controls in each stage of the system. The decision variable x_k includes two arguments: n_k which is the number of control units to be placed in stage k and ℓ_k which is the location of these controls. This decision can be written as:

$$x_k = (n_k, \ell_k) \tag{2}$$

A binary representation of ℓ_k (with 0 = no control and 1 = a control) is used in the optimization process. For example, decision x_k = (2, 010010) means that two control units should be placed in locations 2 and 5.

4) The state transformation function:

The state (error rate) in the system changes when each component in the system performs its function. Let FAIL(input) denote the event that the inputs to the series or branch do include one or more of the predefined errors error. Define FAIL(i^{b_k}) to be the event that operating component i in branch b_k fails to perform its functions. Then for a branch b_k with m operating components, their combined failure rate can be computed as the event E_{b_k} of the failure in the output from branch b_k.

$$E_{b_k} = \text{FAIL(input)} \quad \text{FAIL}(i^{b_k}) \quad \text{FAIL}(i+1^{b_k}) \quad \ldots \quad \text{FAIL}(m^{b_k}) \qquad (3)$$

The computation of this transformation depends on the input failure rate to the branch, and the type of components in the branch. For example, a branch which includes only two operating components will produce a joint failure rate (e_{b_k}) is computed as:

$$\begin{aligned} e_{b_k} = {} & \text{FR(input)} + FR_1 + FR_2 \\ & - [\text{FR(input)} \cdot FR_1 + \text{FR(input)} \cdot FR_2 + FR_1 \cdot FR_2] \\ & + [\text{FR(input)} \cdot FR_1 \cdot FR_2] \end{aligned}$$

where FR_i is the failure rate assigned to the individual component i (b_k was dropped from the right side of the equation because all terms on that side are defined for b_k), and • is the multiplication operator.

If the decision x_k is to place a control (a control means a control unit from now throughout the paper) after component one in branch b_k, then the failure rate in the output from this branch will be affected by this decision. Because the defined control component works like a filter for the errors in the process, the failure rate in the output information from the branch, after placing the control, can be computed as:

$$e_{b_k}\text{(input to control)} = \text{FR(input)} + FR_1 - (\text{FR(input)} \cdot FR_1)$$

$$e_{b_k}\text{(output from control)} = e_{b_k}\text{(input to control)} \cdot \text{FKON}$$

$$e_{b_k}\text{(output from branch)} = [e_{b_k}\text{(output from control)} + FR_2] - [e_{b_k}\text{(output from control)} \cdot FR_2]$$

where FKON is the failure rate of the control.

The overall error rate (state) of the system at the end of stage k (e_k) can be computed as the combined error rate from the different branches in stage k. The volume of information (i.e., number of documents) v_{b_k} will be used as weights in combining the error rate for stage k. The combined error rate can be written as:

$$e_k = \left(\sum_{b_k=1}^{B_k} e_{b_k} \cdot v_{b_k} \right) / \sum_{b_k=1}^{B_k} v_{b_k} \qquad (4)$$

In general, the state transformation function can be written for stage k as:

$$e_k = t_{k-1}\,(e_{k-1},\, x_k) \qquad (5)$$

where t_{k-1} is the transformation operator; e_{k-1} is the input state (error rate) to stage k and x_k is the decision of controls in stage k.

5) Optimization constraints:

In the optimization process only the never-dominating decisions are eliminated while all the dominating decisions (combinations of controls) are provided for management to choose the design of controls that would satisfy their acceptable limits of cost and error rate in the accounting information. Therefore, the maximum cost allowed (budget constraints) or the maximum error rate allowed in the accounting information can be placed as constraints on the set of decisions (designs) obtained from the optimization process.

6) Stage return (cost) function:

The cost function is the total cost of errors as defined above. It includes the operating costs of errors and the loss of misinformation.

Let $C_i^{b_k}$ and $FR_i^{b_k}$ be the respective operating cost and failure rate of the operating component i in branch b of stage k. The two measures are given per volume of information v^{b_k} which is being processed in branch b of stage k. Let $FKON(j^{b_k})$ and $CKON(j^{b_k})$ be the failure rate and cost of control j that is placed in branch b_k, and let $g_k(e_k,x_k)$ be the loss of processing unacceptable information in stage k of the system. This loss can be computed as:

$$g_k(e_k,x_k) = \left\{ \sum_{b_k=1}^{B_k} \sum_{s_{b_k}=1}^{S_{b_k}} \left[\sum_{i=1}^{ns_{b_k}} FR_i \sum_{\ell=1}^{ns_{b_k}} C_\ell \right] \right\} + \sum_{j=1}^{T_{b_k}} FR_j \sum_{z=j}^{T_{b_k}} C_z \qquad (6)$$

where

b_k is branch b in stage k, B_k is the number of branches in stage k,

s_{b_k} is control s in branch b_k. S_{b_k} is the total number of controls in branch b_k,

ns_{b_k} is the number of operating components between control s_{b_k} and the next control $(s+1)_{b_k}$, and

T_{b_k} is the number of operating components between the last control in the branch (S_{b_k}) and the end of the stage k.

In addition, the cost of operating S controls in stage k is computed as:

$$h_k(x_k) = \sum_{s=1}^{S_k} CKON(s) \ , \tag{7}$$

CKON(s) is the operating cost of control s in stage k.

Therefore, <u>the operating cost of the predefined errors in stage k</u> can be written as

$$g_k(e_k, x_k) + h_k(x_k) \tag{8}$$

Define α_{tk} to be the opportunity cost (shadow price) computed by management for using incorrect information in its decision model. Therefore, management should compute, based on its utility function, an α_{tk} for each error type t at the end of each stage k in the system. The loss (cost) of misinformation can then be approximated for a given error at the end of stage k as a linear function of the rate of this given error. That is

$$L(e_{tk}) = \alpha_{tk}(e_{tk}) \tag{9}$$

where (e_{tk}) is the rate of error t in the information at the end of stage k, $L(e_{tk})$ is the cost of misinformation from error rate e_{tk}. The cost of misinformation at the end of stage k can be computed as:

$$L(e_k) = \sum_{t=1}^{T} \alpha_{tk}(e_{tk}) \tag{10}$$

where $L(e_k)$ is the total loss of misinformation from error types t=1, ..., T in the system at the end of stage k.

Therefore, the total cost of errors in stage k can be written as:

$$g_k(e_k,x_k) + h_k(x_k) + L_k(e_k) \tag{11}$$

7) The recursive equation:

Let $f_k(e_k)$ be the minimum total operating cost of the system up to the end of stage k given that the error rate (state) of the system at the end of stage k is e_k. Then, the recursive equation of dynamic programming can be written as:

$$f_k(e_k) = \min_{x_k} \{g_k(e_k,\ x_k) + h_k(x_k) + L_k(e_k) + f_{K-1}(e_{k-1})\} \tag{12}$$

subject to

$$e_k = t_{k-1}(e_{k-1},\ x_k),$$

$$e_0 = 0$$

<u>Assumptions of the Model</u>

Two assumptions were made in the development of the optimization model presented above. First, the performance of the different components are assumed to be independent. Because the model is concerned with unintentional errors only, collusion between components (i.e., fraud) is not assumed. Any error may be recommitted again after it has been corrected as long as the process is in operation.

MODEL APPLICATION

The analysis of the hypothetical payroll system requires management to define the following possible errors for which controls may be designed:

1. Monetary errors in the financial accounting records (i.e., errors in recording the entry or in the amount disclosed in the financcial statements).

2. Monetary errors in cost accounting records resulting from incorrect labor cost allocation.

3. Non-monetary errors in payroll checks.

Once the errors are defined, the system designer should define a path for each of the predefined errors. The error path would include the elements (processes) of the system in which the given error is likely to exist. As a result, the entire accounting system can be redefined as a number of error paths equal to the number of the predefined errors. Therefore, three error paths should be defined in our example. An element (component) in the system may be included in more than one path if it can make more than one error. An illustration of how error paths are defined, specifically error path 2, is given in Appendix 1. When all error paths are analyzed, the results may be combined to provide an overall design of controls for the entire system.

2) Data Requirements

Measures of operating cost and failure rate (C,FR) should be assigned to the individual components based on sampling and observation techniques. These measures should be provided per volume of information in each payroll cycle (i.e., number of documents). The frequency approach may be used in assigning the probability of failure to the different components. Several studies including Yu and Neter (1973) and Cushing (1974) have suggested the use of such techniques in collecting the data requirements. Even though operating cost of the components are easily determined per period of time, it can also be measured per volume of information. In this study, hypothetical data are provided. Some intuitively appealing assumptions were considered in providing this data.

For example, the failure rates assigned to the operating elements range from .020 to point .072 depending on the complexity of the process (function) assigned to the element, and whether it is likely to be a human or a machine element. For control elements (components) it is assumed that the failure rates are lower than for the operating components, and they range from .005 to .035. The operating cost of the elements (both types) are assumed to be adversely related to their failure rates. That is, the higher the failure rate the lower the cost of the element. This is an application to the usual quality-price relationship. The cost of operating the different elements in a given branch is estimated with respect to the volume of information being processed in the branch by the element.

For the analysis of each type of error, a new set of failure rates (probabilities of failure) is assigned to the elements which are in the path defined for that error. If the element is not involved in the path of the error under analysis, a zero probability of failure is assigned to it. However, the operating cost of the element stays the same for all errors. Examples for the assignment of data are given in Appendix 2.

The immaterial amounts of cost and failure rate are defined as $2 and .002 respectively to be used in the refinement of the computation.

3) Computation algorithm and refinements:

Figure 5 shows the computation procedures used in the application of the model to our payroll system example. This algorithm is described in Appendix 3.

A computer program has been developed to carry out the analysis described above. The program is written in FORTRAN-V and can be used in the analysis of a general class of systems with serial and nonserial configurations. The program can handle series configurations, converging and diverging branches, and feedforward loops. Considering that any accounting system can be defined as a combination of these configurations, the program is expected to have general application.

In developing the program, two computational aspects were considered. First, although the model can allow for redundancy of controls, this specific program allows only one control unit after each performance component. Since the control unit is designed to detect/correct a specific error it may be reasonable to assume that with the choice of a high quality control for this specific error, the output of this control may not need to be rechecked by another immediately following control. Second, the operating cost of a control is estimated for a given volume of information. If the total volume of information at the merging point of the output from the different branches (i.e., at the end of the stage) is within the limit on which

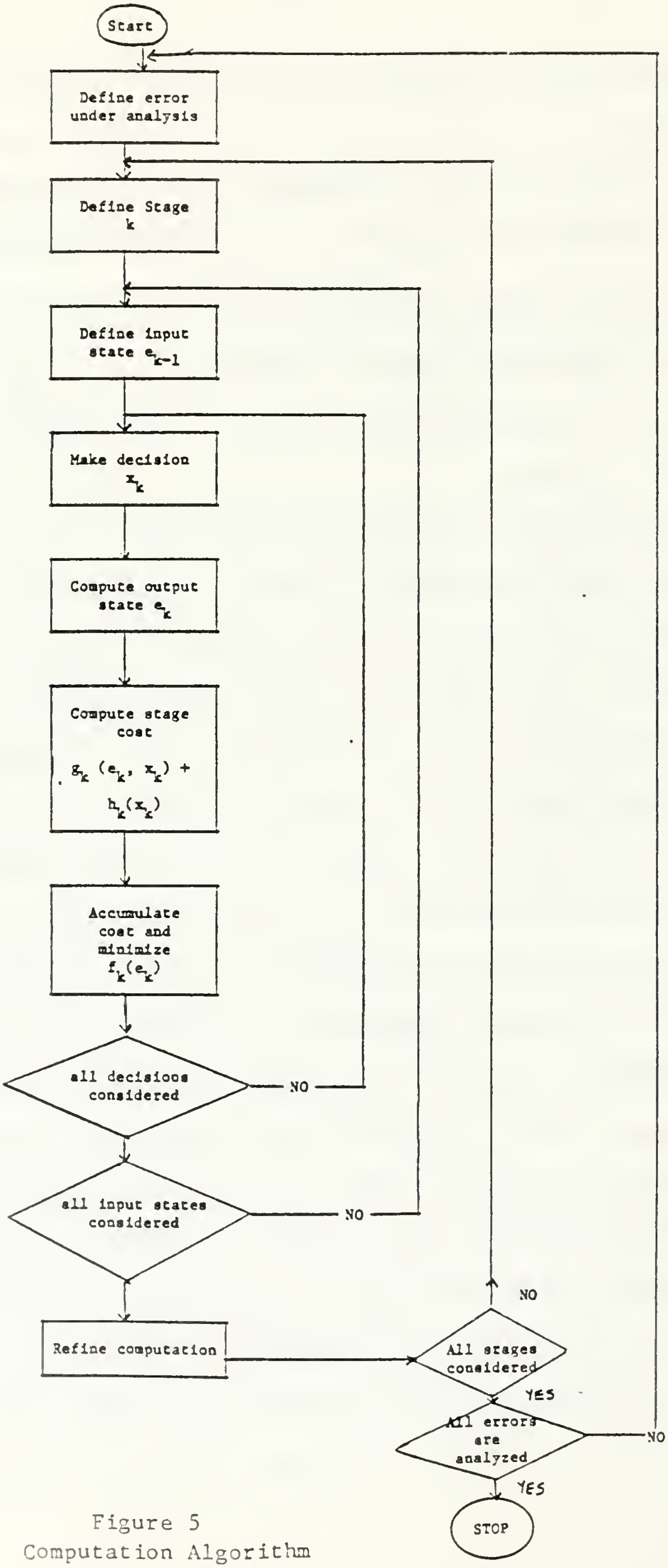


Figure 5
Computation Algorithm

the cost is given, then the merge may be a cost optimum location of control rather than the separate ends of these branches before their merge.

To increase the efficiency of the program some computational refinements (short cuts) are performed when preparing the outputs of the analysis of stage k that are used as inputs in the analysis of the next stage (k+1). Three approaches were used:

a) Elimination of the "never-dominating" decisions (designs) from the output of stage k analysis. The other dominating decisions (to be used in the analysis of the next stage) are the ones that result in lower error rates and lower cost of the system. To illustrate, if $f_k(\bar{e}_k) \le f_k(\bar{\bar{e}}_k)$ <u>and</u> $\bar{e}_k < \bar{\bar{e}}_k$, then $\bar{\bar{x}}_k$ is dominated by $\bar{x}_k$ and therefore $\bar{\bar{e}}_k$ is eliminated from the possible decisions (designs) for the stage k and is not considered in the inputs to the analysis of stage k+1.

b) Elimination of decisions with immaterial differences in their effect on the error rate. For example, the designer may decide that an amount of error rate, say .002, may be sacrificed for lower total cost of the system. In this case, if $\bar{e}_k - \bar{\bar{e}}_k < .002$, then decision $\bar{\bar{x}}_k$ may be eliminated for the lower cost of $\bar{x}_k$ and the immaterially higher error rate $\bar{e}_k$.

c) Elimination of decisions with immaterial difference in cost. The system designer may decide on an amount of cost, say \$2 to be immaterial and could be sacrificed for lower error rate. For example, if $\bar{f}_k(\bar{e}_k) - \bar{\bar{f}}_k(\bar{\bar{e}}_k)$ is less than \$2, then decision $\bar{\bar{x}}_k$ may be eliminated and $\bar{x}_k$ may be kept to provide the lower error rate $\bar{e}_k$ for the immaterially higher cost $\bar{f}_k(\bar{e}_k)$.

If the analyst decides not to eliminate any decisions, he should input zeros as immaterial amounts for both cost and error rate.

ANALYSIS OF RESULTS

The results of the application of the model to the hypothetical payroll system are summarized in Table 1. The results include only the dominating decisions of control in each stage. The table shows both the number and location of controls in each branch of each configuration (stage) in the system as well as whether a control is needed at the end of the stage (the merge). For each error path, a set of dominating decisions of control was obtained. The output table provides, for each decision, the number and location of controls, and the expected failure rate and total cost of errors under the given decision (design). The location of controls is represented by a binary control which is 0 for no controls and 1 for a control. Therefore, if the branch or the stage has 0 it means that the decision is to place no controls in this branch or stage. The decision 0010 means that only one control should be placed in location 3 in this given branch or series (location 3 means after the third operating component in the series or branch).

These results suggest several observations. First, the design that minimizes the failure rate does not necessarily suggest placing controls in each stage of the system (see design 5 for errors 1 and 2, and design 6 for error 3). Second, although the cost of misinformation and the operating cost of errors are functions of error rate, the feasible control design which minimizes the total cost suggests that controls placed early in the system, while the design that minimizes

Table 1

Results of the Analysis of the
Hypothetical Payroll Example:
The Dominating Designs

Design No.		Control Decision in stages k=1, ..., 5 — n_k = no of controls, ℓ_k = location																Error Rate in the Final Output (5)	Total cost of errors $F_5(e_5)$
		n_1	ℓ_1 Branch 1	ℓ_1 Branch 2	ℓ_1 Branch 3	ℓ_1 at merge	n_2	ℓ_2	n_3	ℓ_3 Branch 1	ℓ_3 Branch 2	ℓ_3 at merge	n_4	ℓ_4	n_5	ℓ_5 Branch 1	ℓ_5 Branch 2		
Error 1	1	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	.14268	$4086.25
	2	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	.11972	4430.87
	3	0	0	0	0	0	1	0010	0	0	0	0	1	1	0	0	0	.11691	4490.36
	4	1	0	0	0	1	0	0	1	100	0	0	0	0	1	0	10	.06610	5557.96
	5	1	0	0	0	1	0	0	1	0	0	1	0	0	2	01	10	.06263	5659.02
Error 2	1	0	0	0	0	0	1	0010	0	0	0	0	0	0	0	0	0	.20293	3309.26
	2	0	0	0	0	0	1	0001	0	0	0	0	0	0	0	0	0	.17780	3589.74
	3	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	.14769	3931.34
	4	0	0	0	0	0	1	0010	0	0	0	0	1	10	0	0	0	.11546	4402.10
	5	0	0	0	0	0	1	0010	0	0	0	0	0	0	1	0	10	.06286	5505.01
Error 3	1	0	0	0	0	0	1	0010	0	0	0	0	0	0	0	0	0	.30442	2708.82
	2	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	.14960	3991.02
	3	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	.11952	4419.28
	4	0	0	0	0	0	1	0010	0	0	0	0	1	1	0	0	0	.11667	4475.85
	5	0	0	0	0	0	1	0010	0	0	0	0	0	0	1	0	1	.06587	5542.55
	6	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0	1	.06277	5644.54

the failure rate in the final output suggests placing some controls close to the end of the system (i.e., in the later stages). Third, for the other designs that do not provide minimums (for cost or failure rate) they seem to suggest placing controls in every other stage of the system (see designs 3 and 4 in the analysis of error 1, design 4 in the analysis of error 2, and design 5 and design 2,4 in the analysis of error 3). Fourth, the merge of converging branches or feedforward loops, appears to be a good location for control since it checks on the outputs from the different branches for supposedly less cost than if separate controls were placed at the end of each branch before their merge. The location of control may affect significantly the resulting cost and error rate. For example, designs 1 and 2 in the analysis of error 2 suggest the same number of controls in each branch of each stage of the system. However the two designs differ in the location of the control suggested for stage 2. While design 1 places this control in the third location in the stage, design 2 defines the fourth location as more appropriate for this control. The result of moving the control from location 3 to location 4 is a decrease in failure rate of .02513 and an increase in the cost of errors by $280.48.

Sensitivity Analysis

The validity of the analysis presented in Table 1 depends on the validity of the data provided. One would expect that the value (data) of the parameters of the model would change over time because of the different physical, behavioral, and technical changes in the accounting environment. The following are the results of the sensitivity analysis to measure the effect of such changes in parameters on the performance of the model.

a) Effect of growth in the accounting information process:

Growth is an important objective to every business organization. As a result of the growing activities, the volume of information (i.e., number of documents) is likely to increase. If the increase in volume is within the capacity of the system element, then the cost of the operating components will not change and the set of the dominating decisions does not change. The results of the analysis were not significantly different when the volume of information increased up to 15 percent. The 15 percent growth is assumed to be the maximum addition to the volume of information, which might not require a change in the cost of the operating components.

b) The effect of an increase in cost parameters:

The cost of installing and operating the elements of the system may increase over time because of inflation and other economic factors. An increase of up to 7 percent in the cost of the operating components did not significantly change the results of the model for all of the error paths. However at 8 percent increase in the cost of operating components, one of the dominating decision of controls for error-1 analysis disappeared. The results of the analysis of the other error paths did not significantly change within 1 = 14% increase in the cost of the operating components.

However, an 8 percent increase in the cost of controls was enough to change the results (basically increase or decrease the dominating designs of controls) with respect to error path 1 and 3 and 11 percent increase changed the set of dominating decisions for error path 2.

These findings may support the proposition that the larger (more elements) the path of the error the more sensitive the results to the change in the cost of the elements on this path. However, the change in cost is not expected to exceed 5-6 percent each year (this normally is the raise given to human elements and approximately the increase in the price of machine elements) which will be within the limits in which the results of the model did not significantly change. Therefore, a new analysis of the system may be needed at least every year.

c) Effects of the deterioration in performance level of the components:

The performance of the system components (operating and control) is expected to deteriorate over time because of the aging effect on the machine components, and also the exhaustion, fatigue and other psychological effects on human components. On the other hand, the performance of the system (its reliability) may improve if learning exists. However a system that "consists of several components that are different in nature [machine and human] and every component has a different pattern of performance over time, and the reliability of the system is the combined behavior of its components, then the behavior of this system over time is likely to take the shape of exponential distribution" (Barlow and Proschan, 1963, p. 16). Therefore, in the absence of a descriptive theory of the AIS behavior, it is reasonable to assume that the performance of the components deteriorate over time.

A 5 percent deterioration (increase in failure rate) of the operating components has resulted in a smaller set of dominating decisions for error path 1 and 3 (one decision of control was eliminated from the set). However the set of controls for the second error path did not change with up to 11 percent increase in the cost of the operating components. Because error path 2 does not include as many performance elements as the other two paths, this again shows that the model is sensitive to the longer paths.

Considering the deterioration of the controls (i.e., increasing their failure rate), the 5 percent deterioration was not enough to reduce the set of the dominating decisons obtained from the original data. However only percent deterioration changed the results of error path 1 and 8 percent changed the results of the other error paths.

Conclusions and Limitations of the Study

In this study a dynamic programming model was developed to be used by management (internal auditors) or external auditors in identifying alternatives regarding how many and where to place controls in the AIS such that the performance of the system (cost and error rate) is within the acceptable limits. The model provides a range of feasible designs of control for management to select the most appropriate for the environment. The model relies heavily on the judgements of the analyst in providing the data especially when defining the cost of misinformation. However, since judgement is currently the most common approach in the analysis and evaluation of accounting controls, the judgemental data needed for the model are not expected to be a new and significant problem. On the other hand, the model is intended to serve as a tool (more structured and rigorous) to aid management in making more informed judgements regarding the design of accounting controls and not to replace these judgements. The preliminary results of the model suggest that the location (rather than the number) of controls may have more significant impact on the overall performance of the AIS. The results may also be more sensitive to the change in the cost of the elements as their failure rate in the longer paths (with more elements) than in the shorter ones.

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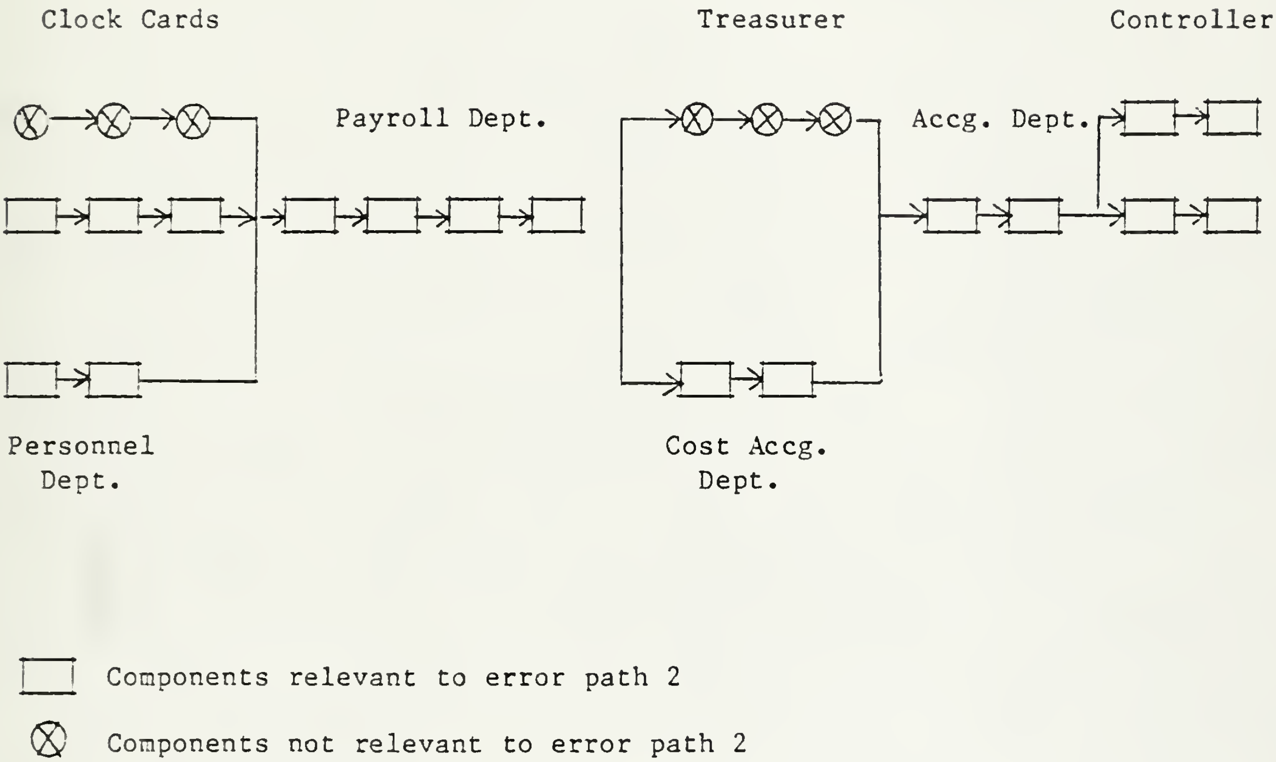
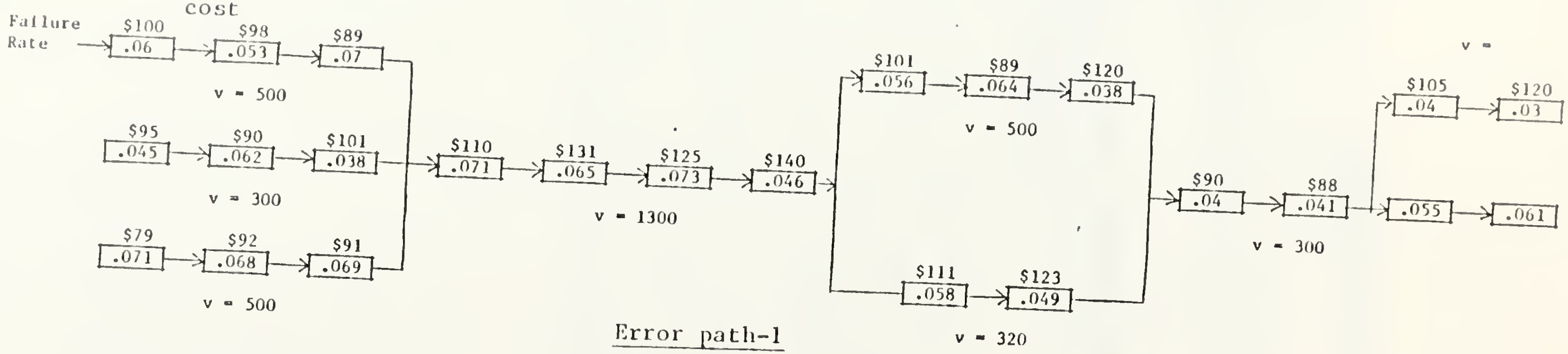
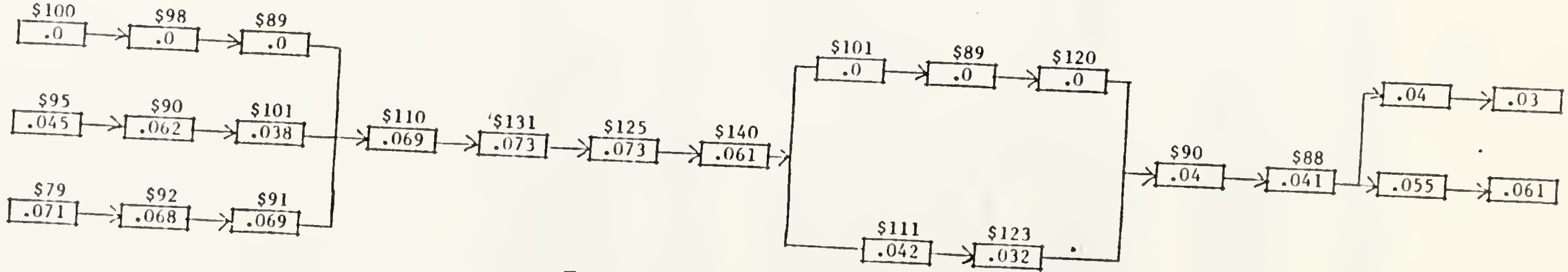
Appendix 1: Definition of Error Path 2



Appendix 2: Hypothetical Data Assignment



Error path-1



Error path-2